The Grid of the Future

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Grid Renovation Workshop

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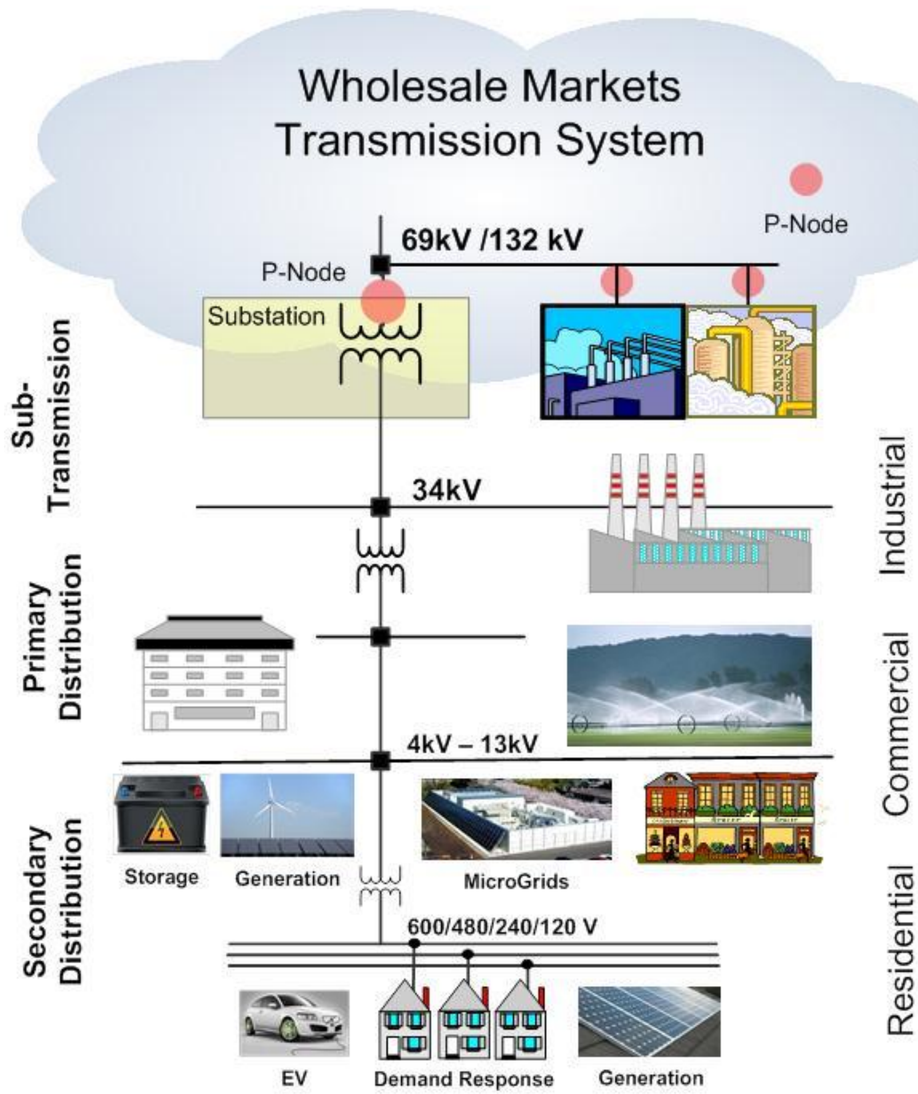
Session 2

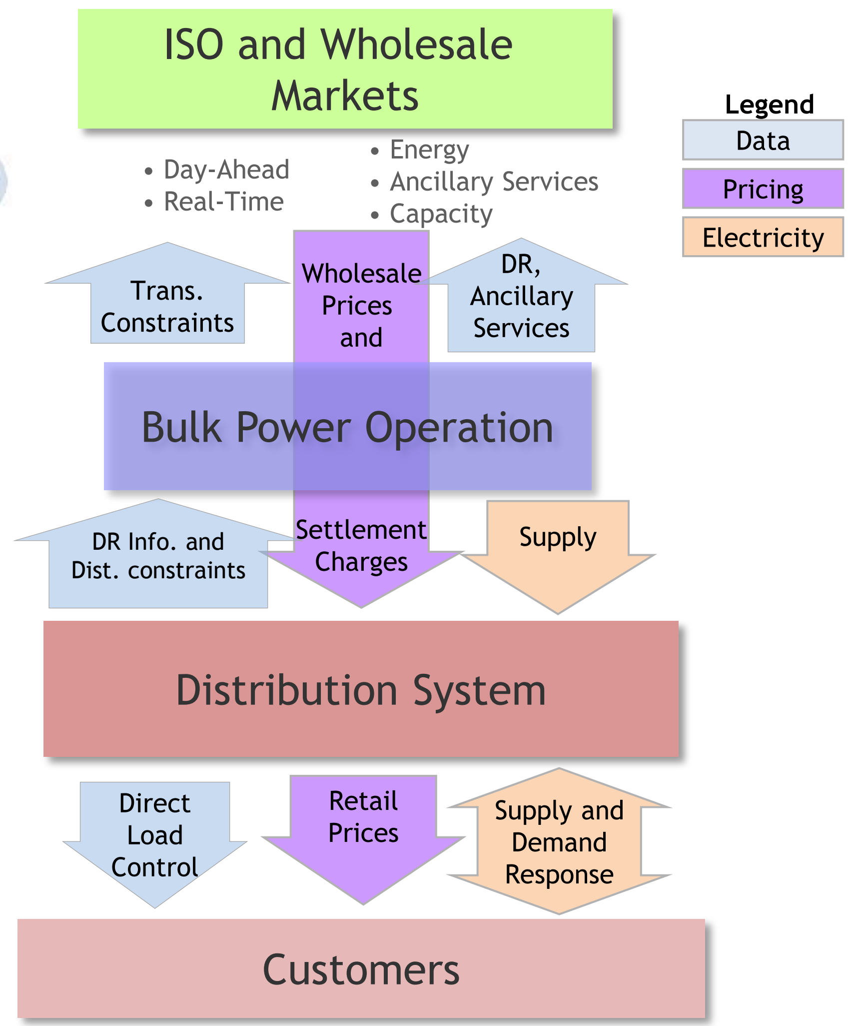
Agenda

- Session 1 75 Minutes
  - Introductions
  - Driving forces changing the electric utility landscape
  - The impacts of the proliferation of Variable Energy Resources (VER)
  - Operational challenges at the wholesale/transmission and at retail/distribution levels
  - Increased visibility and situational awareness requirements at the distribution level
  - Using Advanced AMI and customer data to increase visibility to last mile distribution circuits
  - Managing Demand Response (DR) and Distributed Energy Resources (DER)
- Break 15 Minutes
- Session 2 75 Minutes
  - A new construct: Distribution System Operator (DSO)/Distrusted System Platform (DSP)
    - Overall Description
    - Implementation
  - The emerging Transactive Energy paradigm and its convergence with DSO/DSP constructs
- Break 15 Minutes
- Session 3 60 Minutes
  - Illustrative examples and case studies
  - Concluding Remarks/Question and Answer

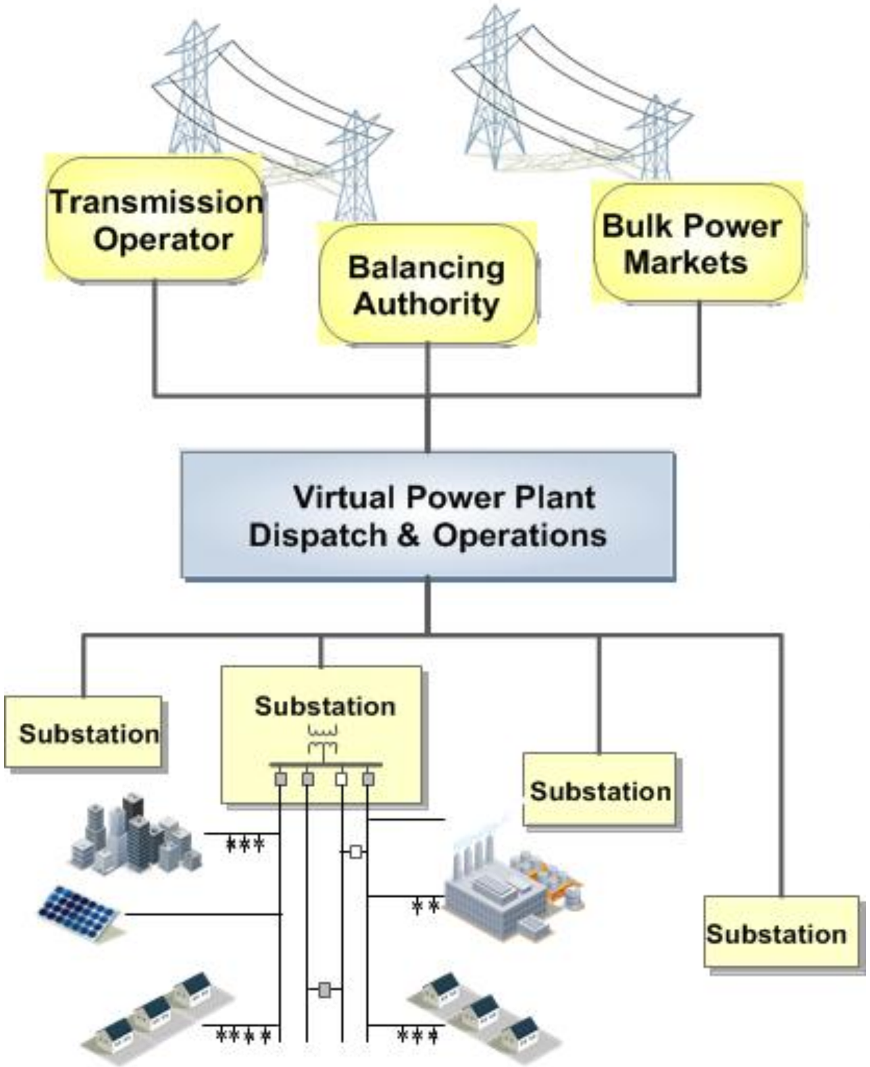
Experience with Use of DR/DER in Wholesale Markets

End-to-End Operational Transactions





Linking Demand-Side Capabilities to Wholesale Operations – Virtual Power Plant (VPP) Construct



Bulk Power Products

- Hour-Ahead Firm
- Non Spin
- Spinning Reserves
- Market-Based Prices

Virtual Power Plant

- Grid Location
- P_{MAX} , P_{MIN}
- Ramp Rate
- Min/Max Up and Down Time
- Incremental Cost Curve

Retail Tariff

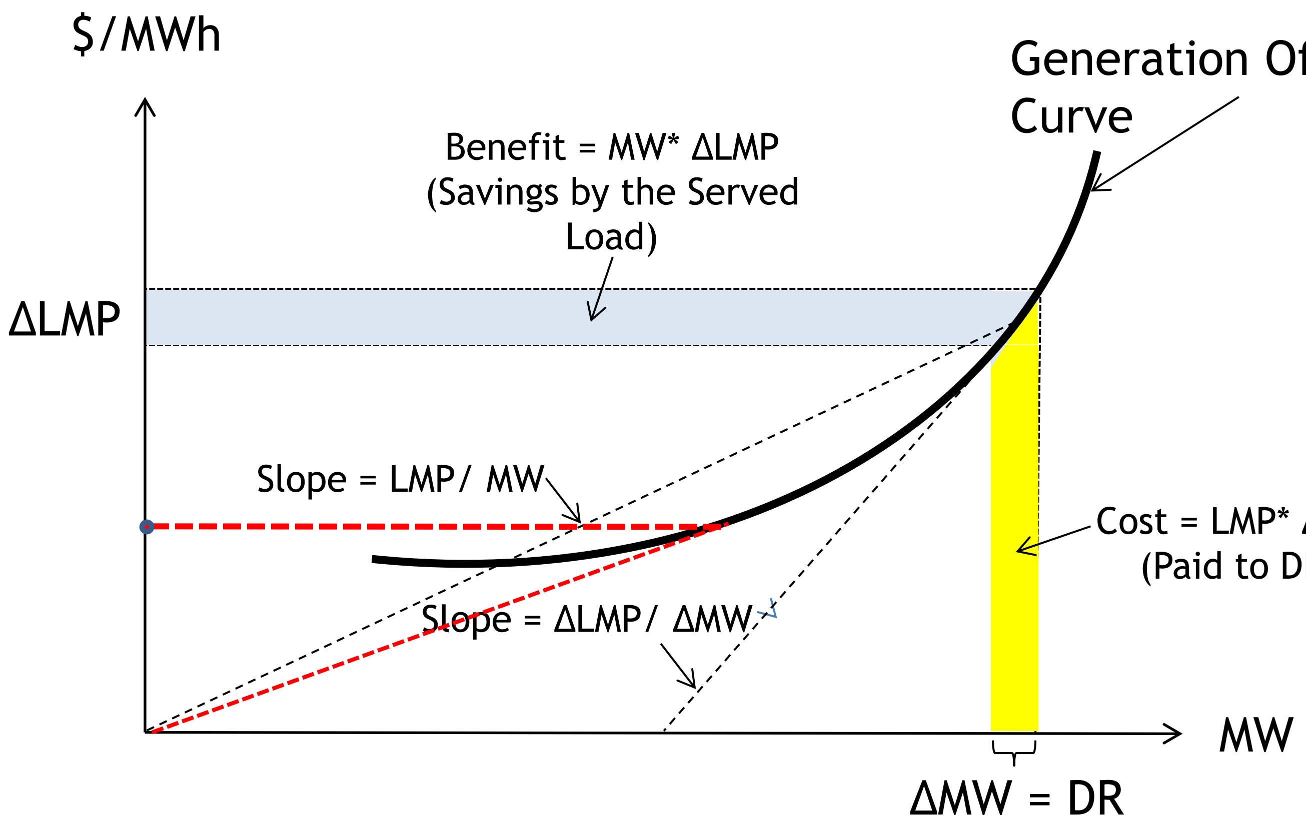
- Direct Load Control
- Time of Use
- Critical Peak Price
- Dynamic Pricing
- Commercial and Industrial Curtailment Contracts
- Etc.

Examples of Government Directives to Enable the Use of DR/DER for Bulk Power Operation

- **FERC Order 719** – ISOs Treatment of DR
  - *Equal Treatment of Supply and Demand Side Resources for provision of Ancillary Services*
  - *Aggregators of Retail Customers (ARC) also known as Curtailment Service Providers (CSP)*
- **FERC Order 745 - DR Compensation**
  - *DR must be paid Locational Marginal Pricing (LMP) if it clears ISO Energy Market and its Cost is less than its benefit to the market*
  - *Net Benefit Test*

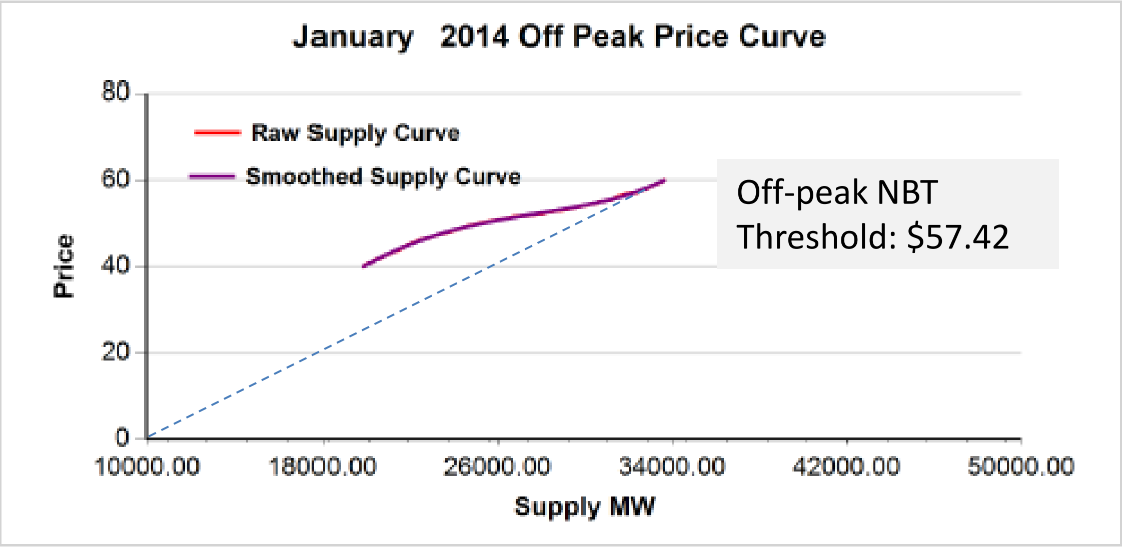
Net Benefit Test

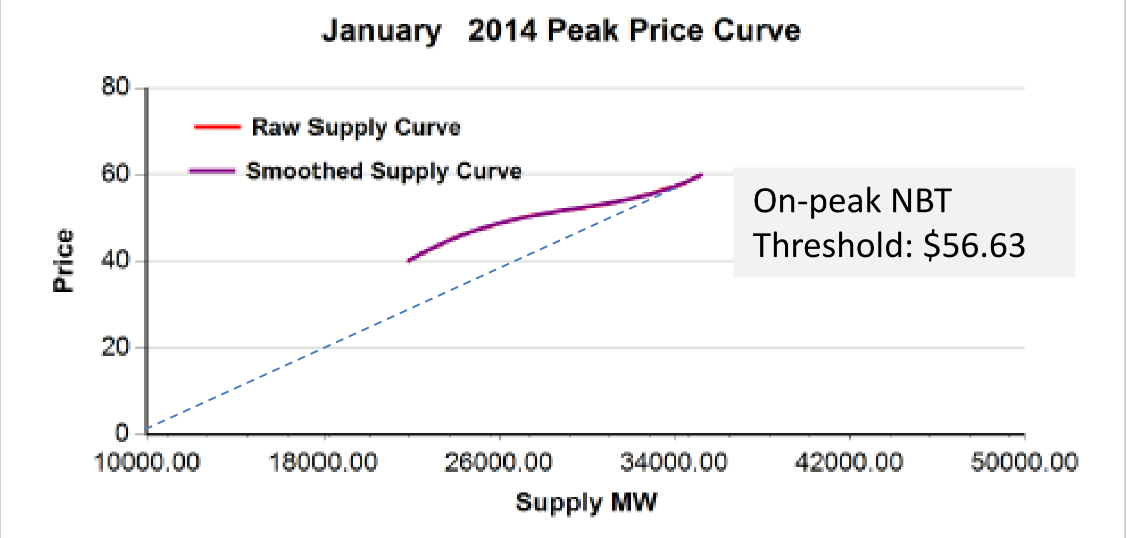
FERC Order 745 (March 2011): DR to be paid LMP subject to Benefit > Cost



Benefit > Cost means MW*ΔLMP > LMP*ΔMW, i.e.
ΔLMP/ ΔMW > LMP/MW

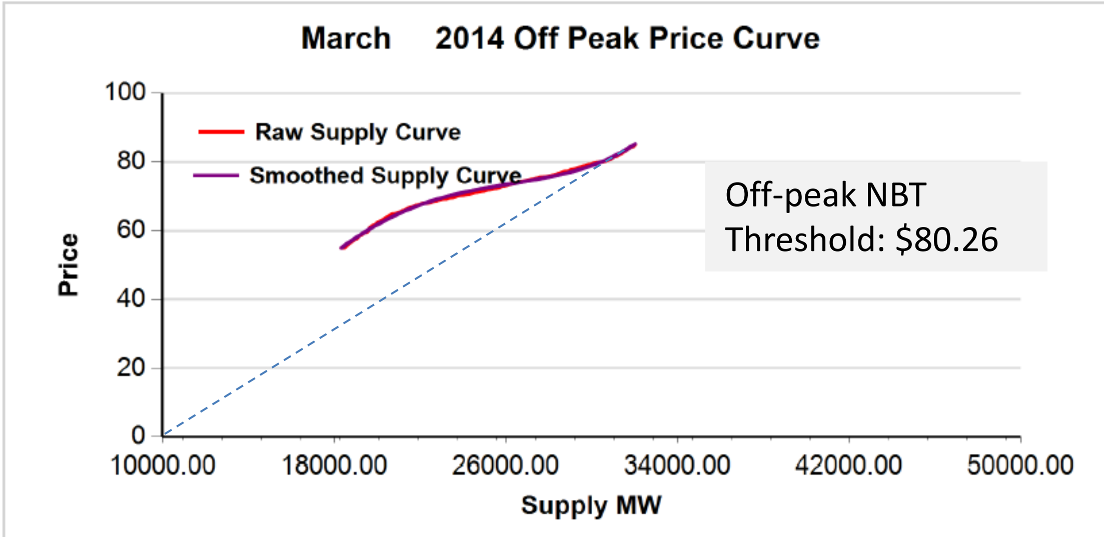
CAISO NBT Thresholds for January 2014

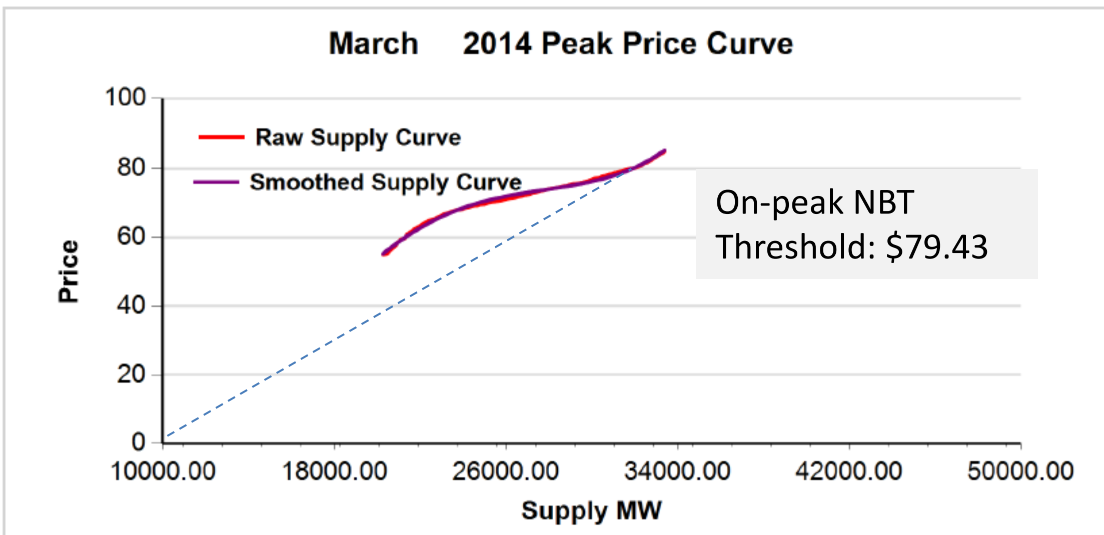




Source: CAISO Monthly Demand Response Net Benefit Test Results for January 2014; published Dec. 10, 2013

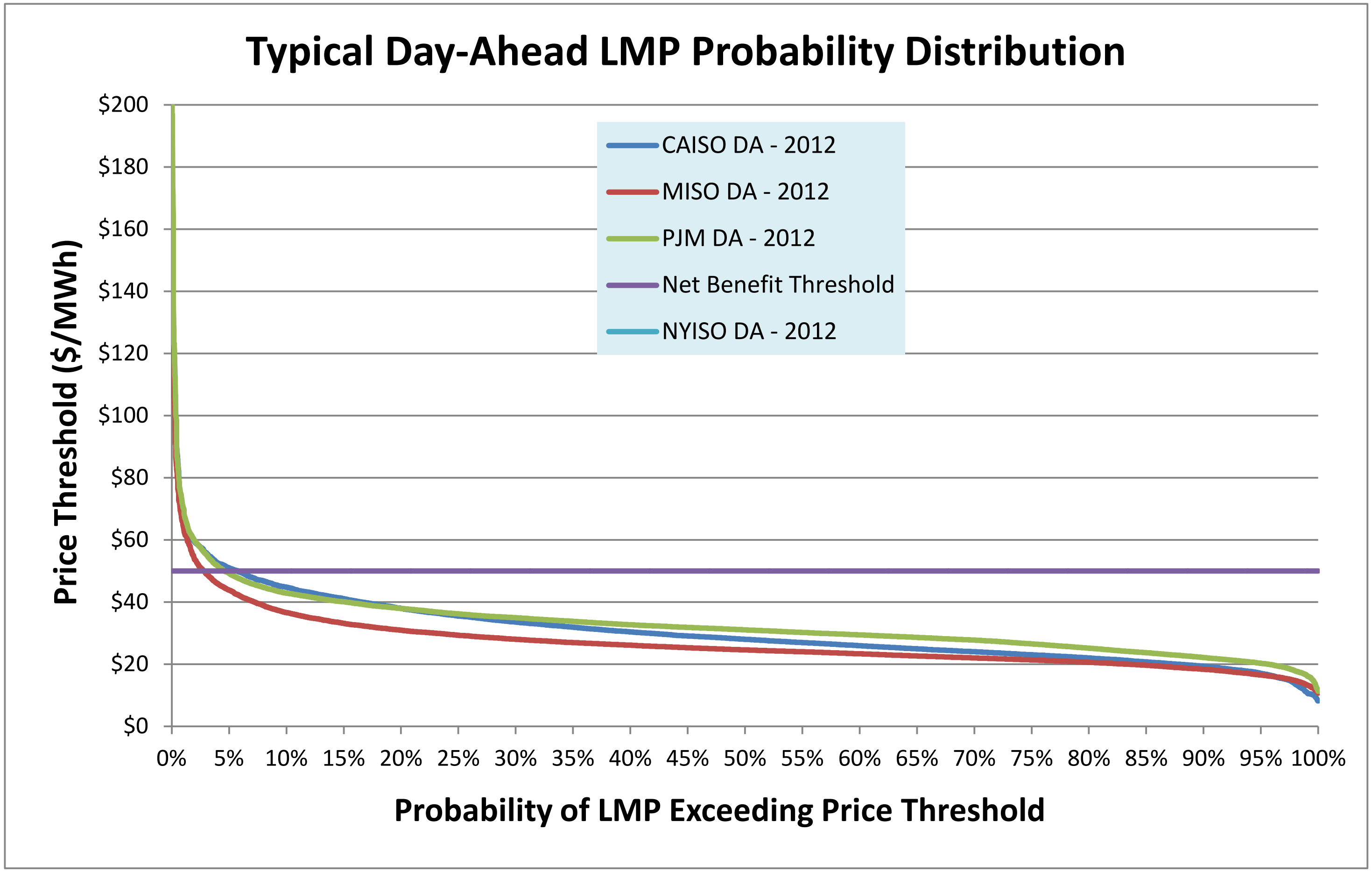
CAISO NBT Thresholds for March 2014





Source: CAISO Monthly Demand Response Net Benefit Test Results for March 2014; published Feb. 11, 2014

Potential Energy Revenues of DR (DA Markets)

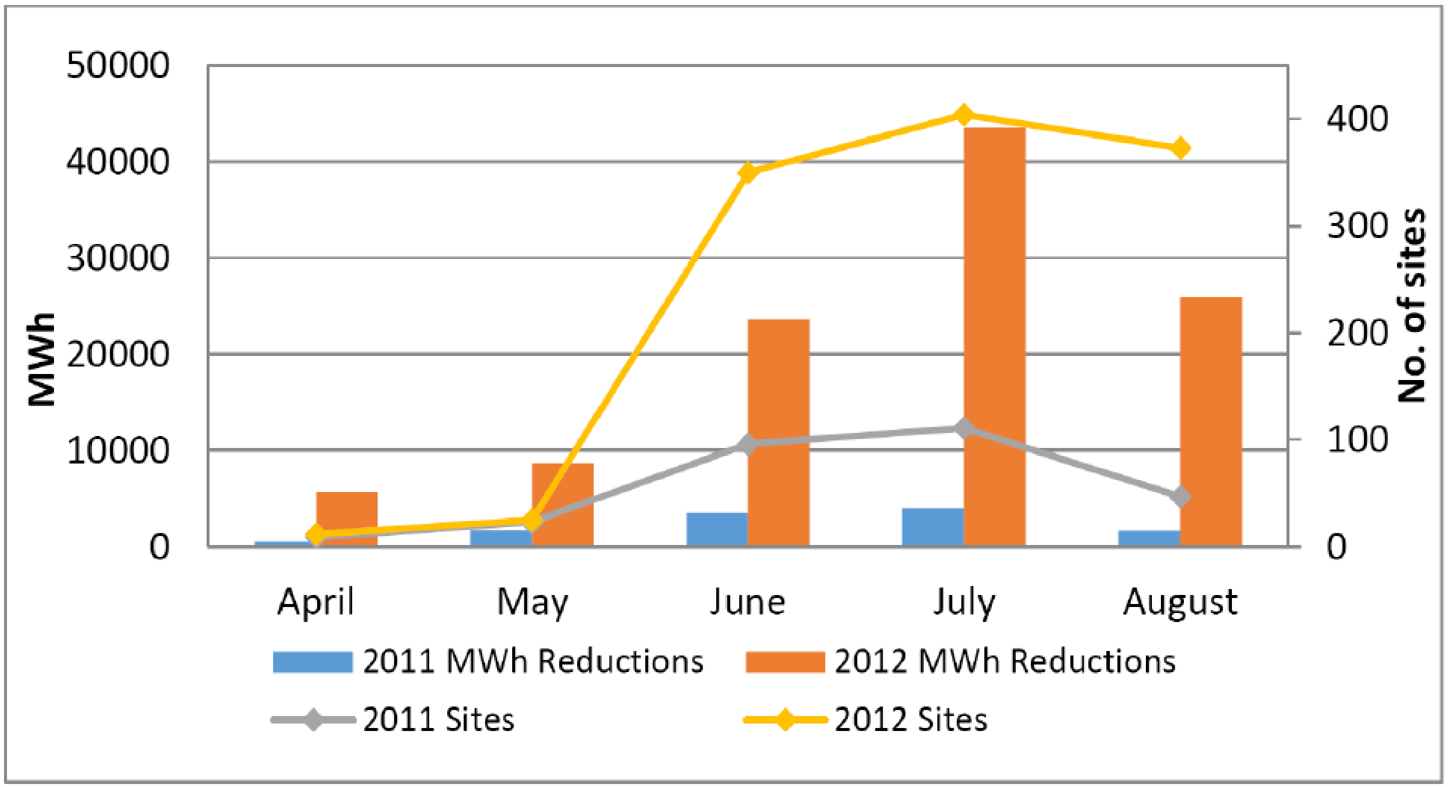


Net Benefit Test Threshold	$50			
Expected Day-Ahead DR Revenues	CAISO	MISO	PJM	NYISO
Total DA DR Rev above NBT Threshold	$31,436	$16,273	$26,834	$36,632

Impact of FERC Order 745

- FERC Order 745 Issued March 15, 2011
- Implemented at PJM Starting Summer 2012

PJM Economic DR Participation Increased Eightfold Following Order 745



Source: Association for Demand Response & Smart Grid Presentation on July 08, 2014 based on EnerKnol Analysis of PJM Data

Product Differentiation

- Retail/Distribution Operation
  - Energy Differentiated by
    - Speed of response
    - Minimum size
    - Directional change
    - Automatic vs manual control
- Need to map Retail Capabilities to Bulk Power Operations Services
  - Energy
  - Capacity (Forward Market-based Auctions; Resource Adequacy Requirements)
  - Ancillary Services
    - Non-Spinning/Supplemental Reserve (10 minutes; 30 minutes)
    - Spinning Reserve (10 minutes)
    - Regulation (5 to 10 minute ramp; 4-second response)
  - Emerging Flexibility Reserves (5 to 15 minute: Ramping; Load Following)

Demand-Side Programs and Wholesale Products

Demand-Side Programs

Wholesale Products			Non-Dispatchable: Voluntary	Non-Dispatchable: Voluntary – Noti-fication	Dispatchable: Demand-limiting Control	Dispatchable: Demand-limiting Control – Notification	Dispatchable: Firm Commit-ment – Notification	Dispatchable: Direct Load Control (DLC) – Notification	Dispatchable: Direct Load Control (DLC)	Dispatchable: Conservation Voltage Regulation
Economic	Capacity	Conventional	Maybe	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Economic	Capacity	Flexible	Maybe	Maybe	Yes	Yes	Yes	Yes	Yes	Yes
Economic	Energy	Day Ahead	Maybe	Maybe	Maybe	Yes	Yes	Yes	Yes	Yes
Economic	Energy	Real-time				Maybe	Yes	Yes	Yes	Yes
Reliability	Ancillary Services	30 Min Non-Spin				Maybe	Yes	Yes	Yes	Yes
Reliability	Ancillary Services	10 Min Non-Spin				Maybe	Maybe	Yes	Yes	Yes
Reliability	Ancillary Services	10 Min Spin						Yes	Yes	Yes
Reliability	Ancillary Services	Regulation						Maybe	Yes	Maybe
Reliability	Balancing (New)	Ramping						Maybe	Yes	Maybe
Reliability	Balancing (New)	Flexibility Reserve						Maybe	Yes	Maybe

Typical Ancillary Service and Capacity Values

ISO/RTO	CAISO	PJM	MISO	NYISO (WEST)
Ancillary Services (Average Prices):				
Non-Spinning Res. ($/MW/h)	$1.50	$1.00	$1.50	$0.99
Spinning Res. ($/MW/h)	$5.00	$7.00	$4.00	$4.34
Regulation ($/MW/h)	$10.00	$15.00	$12.00	$9.73
Capacity Value ($/kW-yr)	$25.00	$40.00	$2.00	$54.00

Expected Annual Values ($/MW DR/yr)	CAISO	PJM	MISO	NYISO (WEST)
Ancillary Services:				
Non-Spinning Res.	$13,000	$8,000	$13,000	$8,000
Spinning Res.	$43,000	$61,000	$35,000	$38,000
Regulation	$87,000	$131,000	$105,000	$85,000
Capacity	$25,000	$40,000	$2,000	$54,000
Flexibility Reserves (Expected Range per MW-Year)	$15,000 - $75,000			

Experience with DR Participation in North American ISO Markets

- ISO Control Room operators do not feel comfortable relying on DR to actually deliver when dispatched
- Distribution utilities do not feel comfortable with third party Curtailment Service Providers signing up their customers just for DR

DSO/DSP Construct

Consideration of Power System Characteristics for End-to-End Operation

- Power system characteristics can impact delivery of transacted quantities from distributed DR/DER assets
  - *Reactive power/voltage impacts*
  - *Phase unbalance impacts*
  - *Impact of distribution losses*
  - *Impact of distribution congestion*
- Bulk Power/Wholesale Operator is oblivious to such distribution system impacts associated with its DR/DER resource scheduling and dispatch
- Distribution Management Systems (DMS) can help determine such impacts
- Distribution System Operator (DSO) can act as facilitator to ensure such impacts are avoided or mitigated

Example: Distribution Grid Volt/Var Effect on Available DR

- Use Case
  - *Feeder Voltage: 13.8 kV*
  - *Feeder Base Load: 9 MW with Unity Power Factor: 3 MW Constant Impedance (Z); 3 MW Constant Current (I); 3 MW Constant Power (P)*
  - *Participating DR: 900 kW with 0.8 Lag Power Factor*
  - *Remaining load after deployment of DR: 8,100 kW with Lead Power Factor*
  - *Feeder Voltage Increase due to Lead Power Factor: 1.5%*
  - *Increase in base load due to voltage increase: 135 kW*
  - *Net Demand Reduction: 900-135 = 765 kW*

Voltage Increase (%)	Z Load	I Load	P Load	Total
1.5%	3%	1.5%	0%	
	90 kW	45 kW	-	135 KW

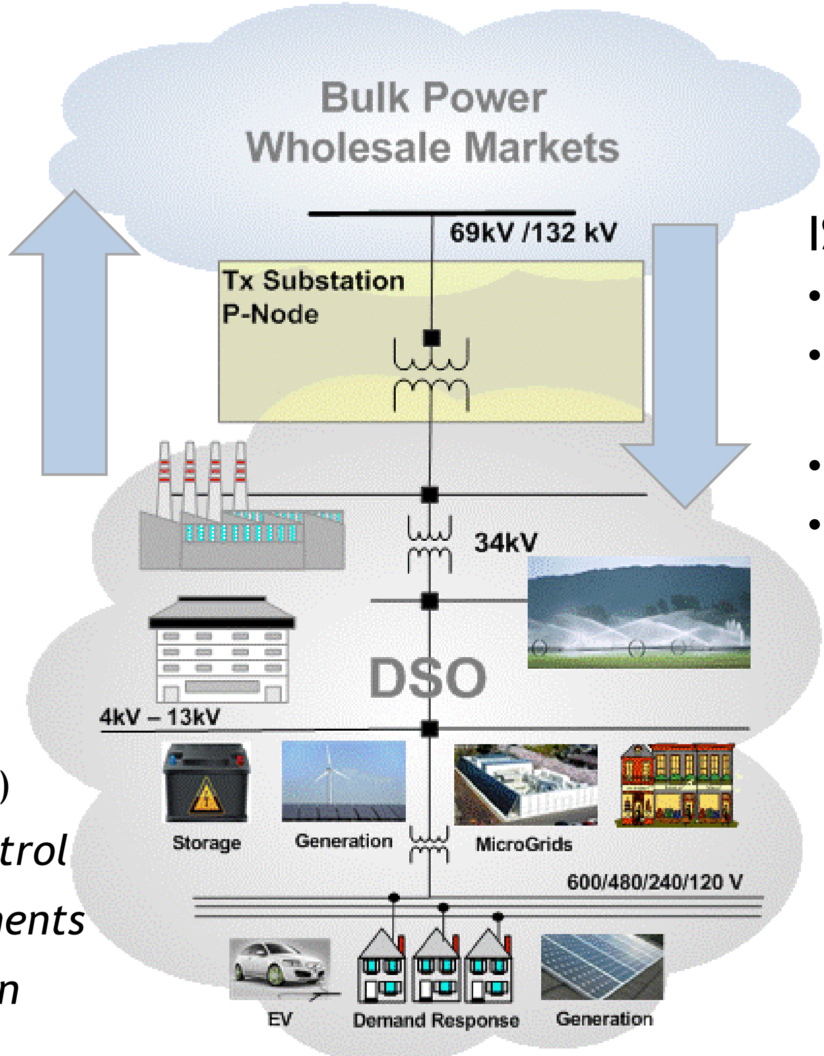
Example: Operational Impact of Phase-Unbalanced DR

- Use Case:
  - *Feeder Voltage: 13.8 kV*
  - *Feeder Base Load: 9 MW phase-balanced (3 MW per phase)*
  - *Participating Demand Response: 900 kW with different amounts on each phase: 300 kW on Phase A; 100 kW on Phase B; 500 kW on Phase C*
  - *For simplicity, assume both the base load and the DR are unity power factor*
  - *When the 900 kW DR is deployed, the remaining load will no longer be phase-balanced*
  - *This results in neutral current and losses for the remaining load; thus reducing the effective DR*
  - *For a system operator, it is important to know the expected effective DR beforehand*
  - *With 1% Neutral Losses for Remaining Load, Net Demand Reduction: 900 - 1%*8,100 = 819 kW*

The DSO Construct – Linking Bulk Power and Distributed Resource Operations

- DSO to ISO/RTO
  - *Forecast Net Load and Dispatchable Products*
  - *Schedules and Bids*
  - *Metering and Telemetry*

- DSO Functions
  - *Distribution Planning*
  - *Distribution Reliability*
  - *Operations Scheduling*
    - Forecasting (Load, DR, DER)
    - Scheduling (DR, DER, Market)
  - *Dispatch and Real-Time Control*
  - *Retail Metering and Settlements*
  - *Retail Market Administration*



ISO/RTO to DSO
- *Schedules*
- *Dispatch Instructions*
- *Prices*
- *Settlements*

DSO Construct

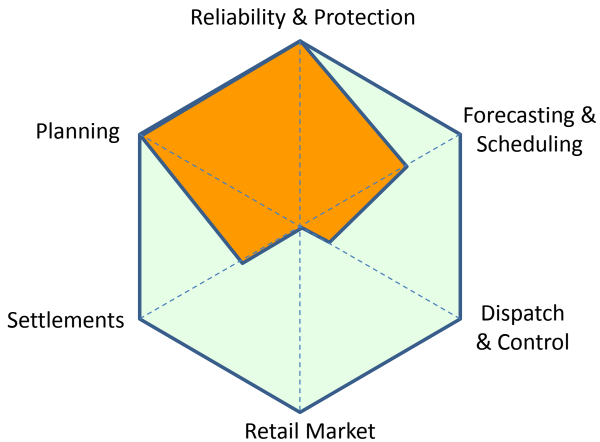
- Basic Responsibilities
  - *Distribution System Planning*
  - *Distribution System Reliability/Protection*
- Possible Responsibilities as Linkage Between Bulk Power/Wholesale and End-Use/Retail Market
  - *Operations Scheduling*
    - Forecasting and Availability Assessment (Load; DR; DER)
    - Aggregation; Virtual Power Plant Creation (Aggregation of distributed demand-side capabilities for provision of different products such as Energy, Ancillary Services, Flexible Ramping, etc.)
    - Scheduling/Bidding into Wholesale Market
  - *Dispatch and Real-Time Control*
    - DR/DER Resource Dispatch
    - Real-time Control
    - Interchange Management (MSS or Pseudo-BA function)

DSO Construct (Continued)

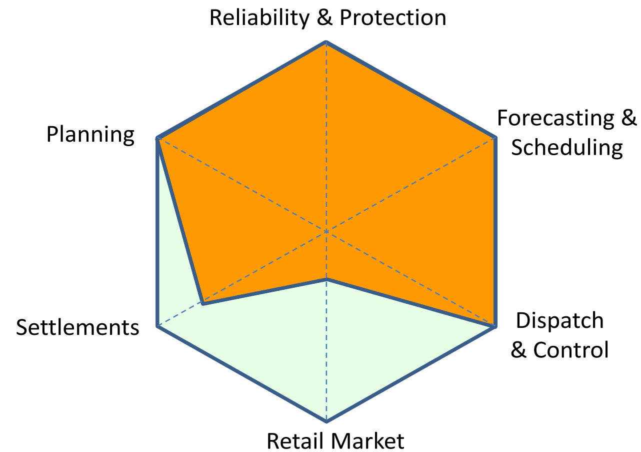
- Possible Responsibilities as Linkage Between Bulk Power/Wholesale and End-Use /Retail Market (continued)
  - *Metering and Settlements*
    - Interval Metering
    - Measurement and Verification
    - Settlement with Bulk Power/Wholesale Market Operator
    - Settlement with DR/DER asset operators
  - *Retail Market Administration*
    - DR/DER Programs
    - DR/DER offers (single buyer)
    - Bilateral DR/DER (Full Transactive)

Different DSO Models

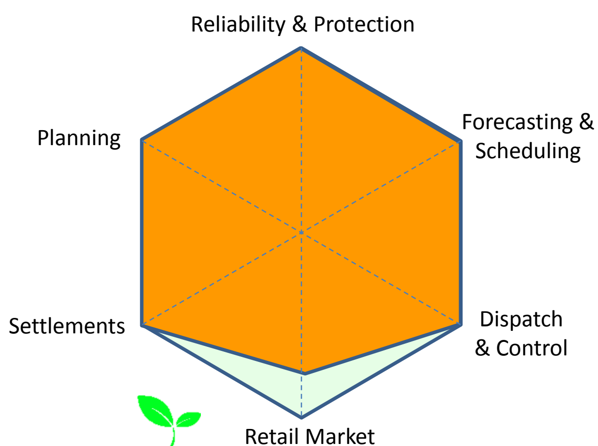
DSO-Lite



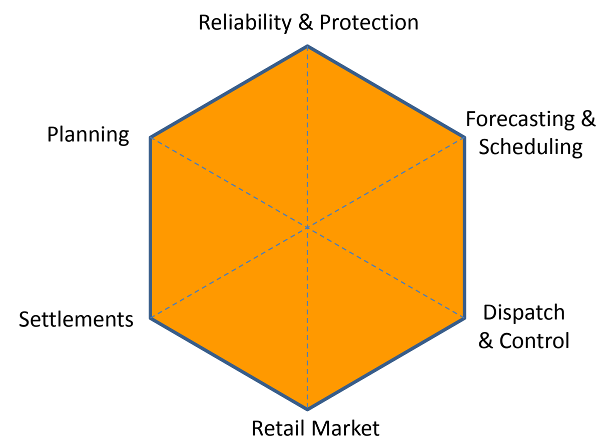
Pseudo BA DSO



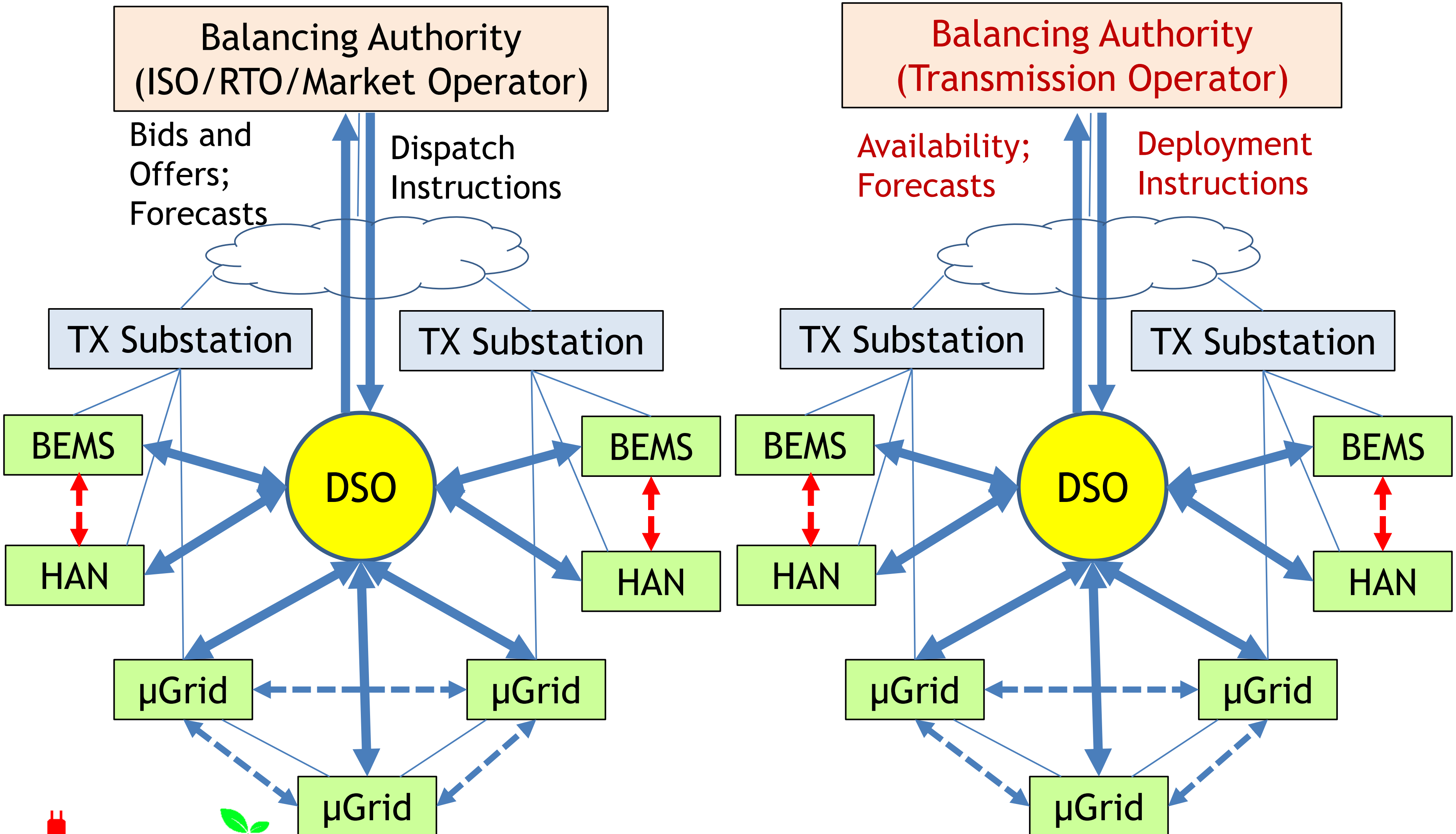
Comprehensive DSO



Maximalist (Fully Transactive) DSO



DSO as Retail/Transactive Facilitator



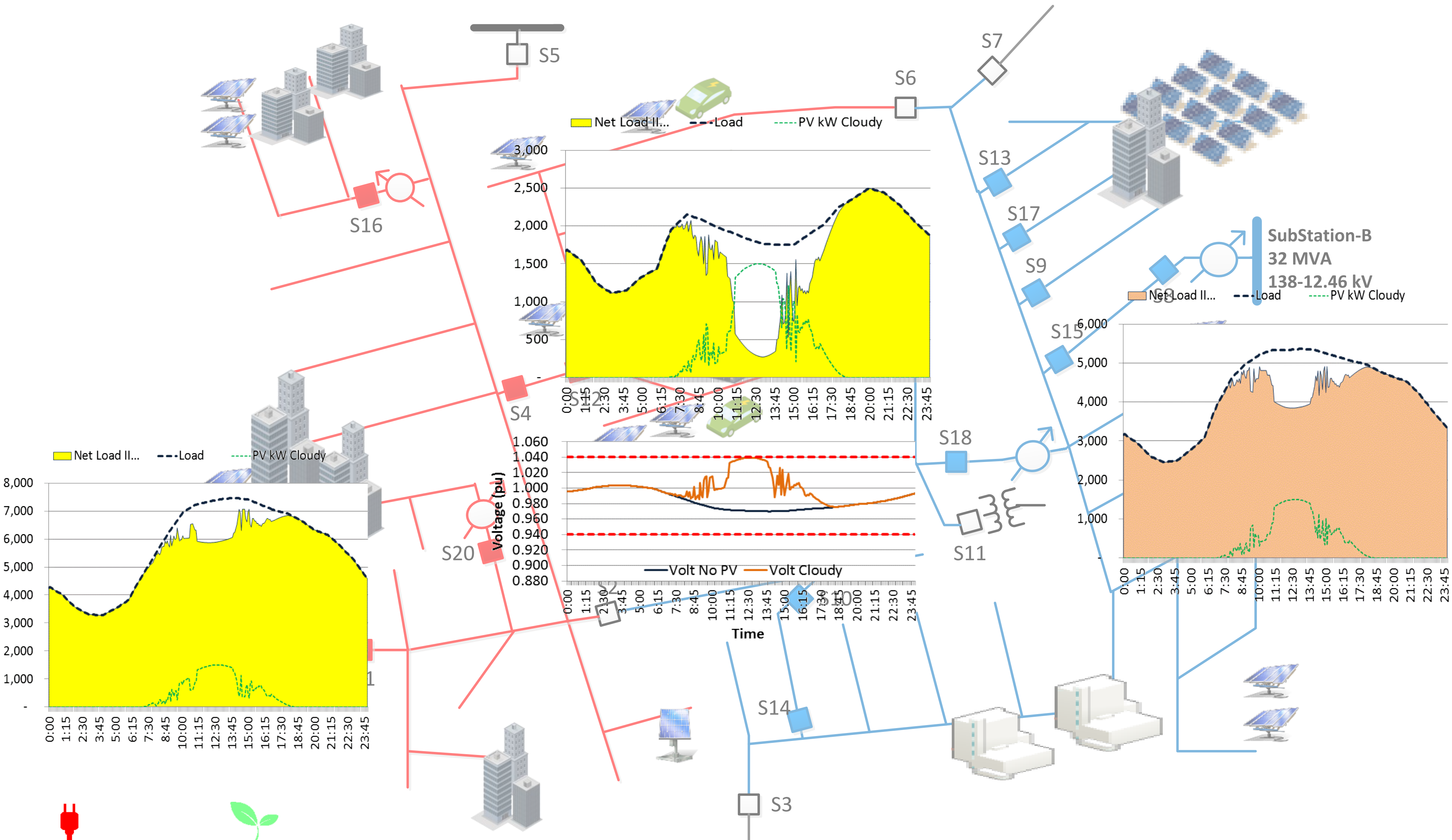
Functionality Timeline

Timeframes

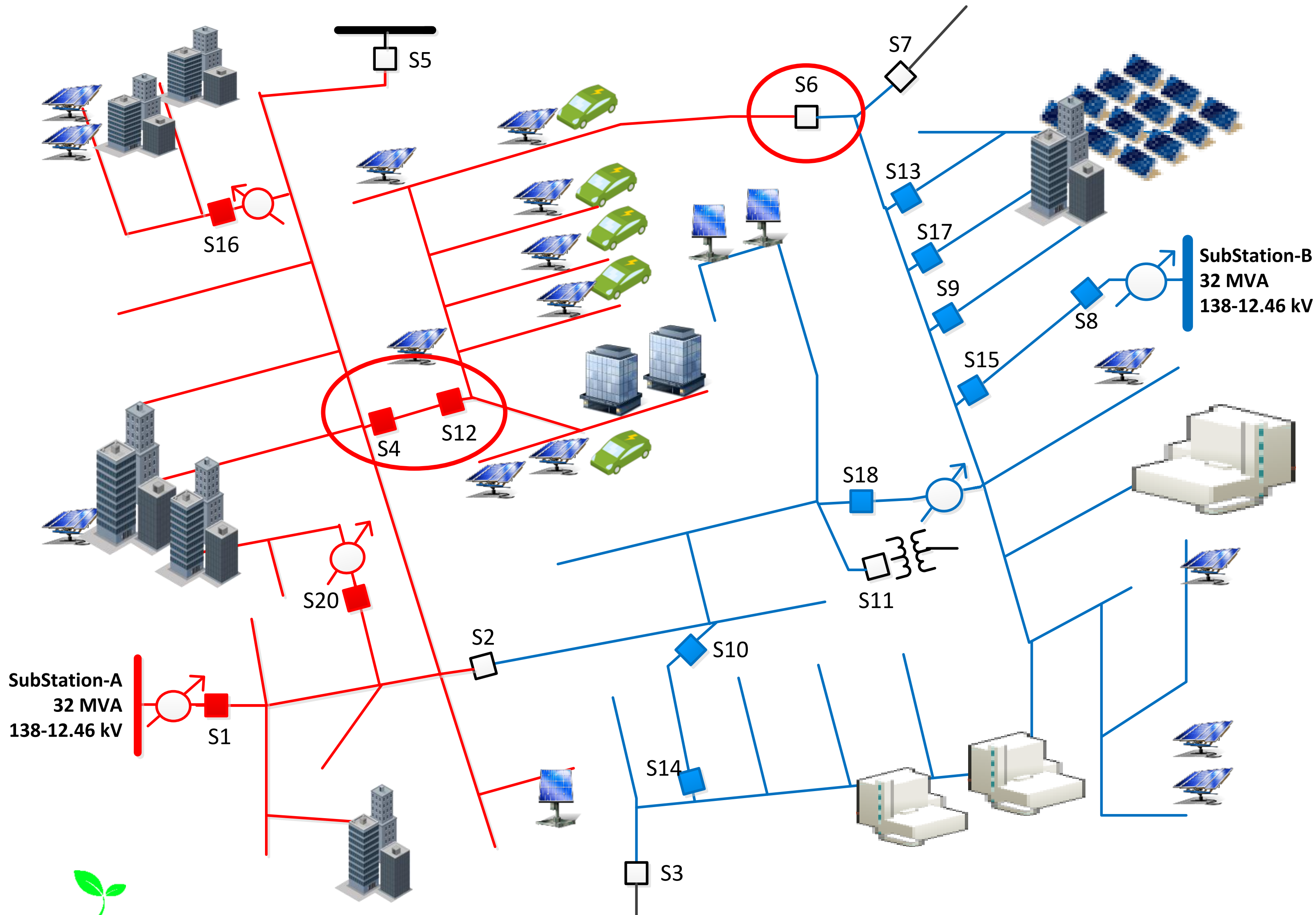
Functions

	Months Ahead	Days Ahead	Hours Ahead	Real-Time	Post Operations
Planning & Resource Adequacy					
Forecasting					
Market/TE Facilitation					
Scheduling					
Dispatch & Control					
M&V and Settlements					

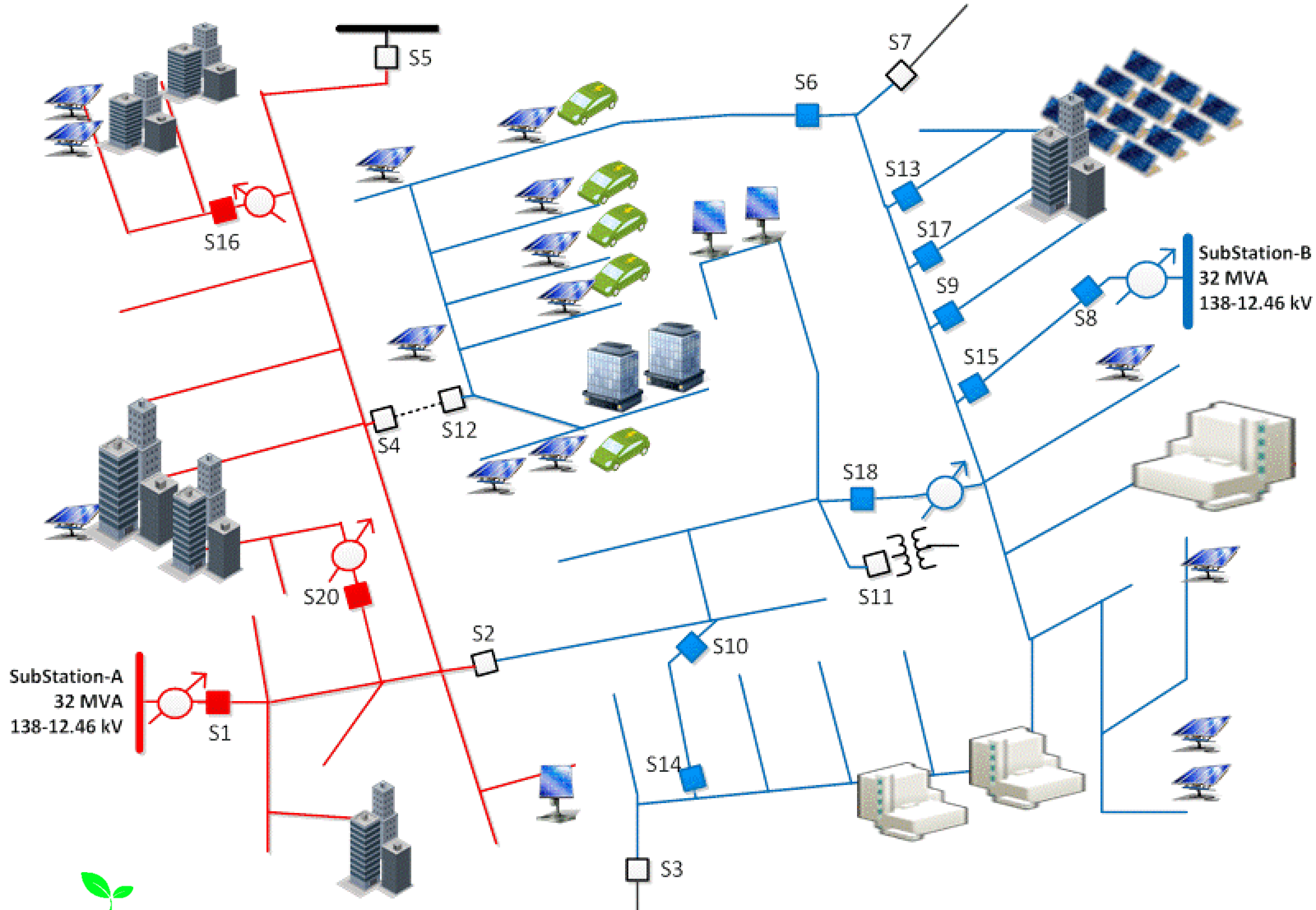
Illustrative Example



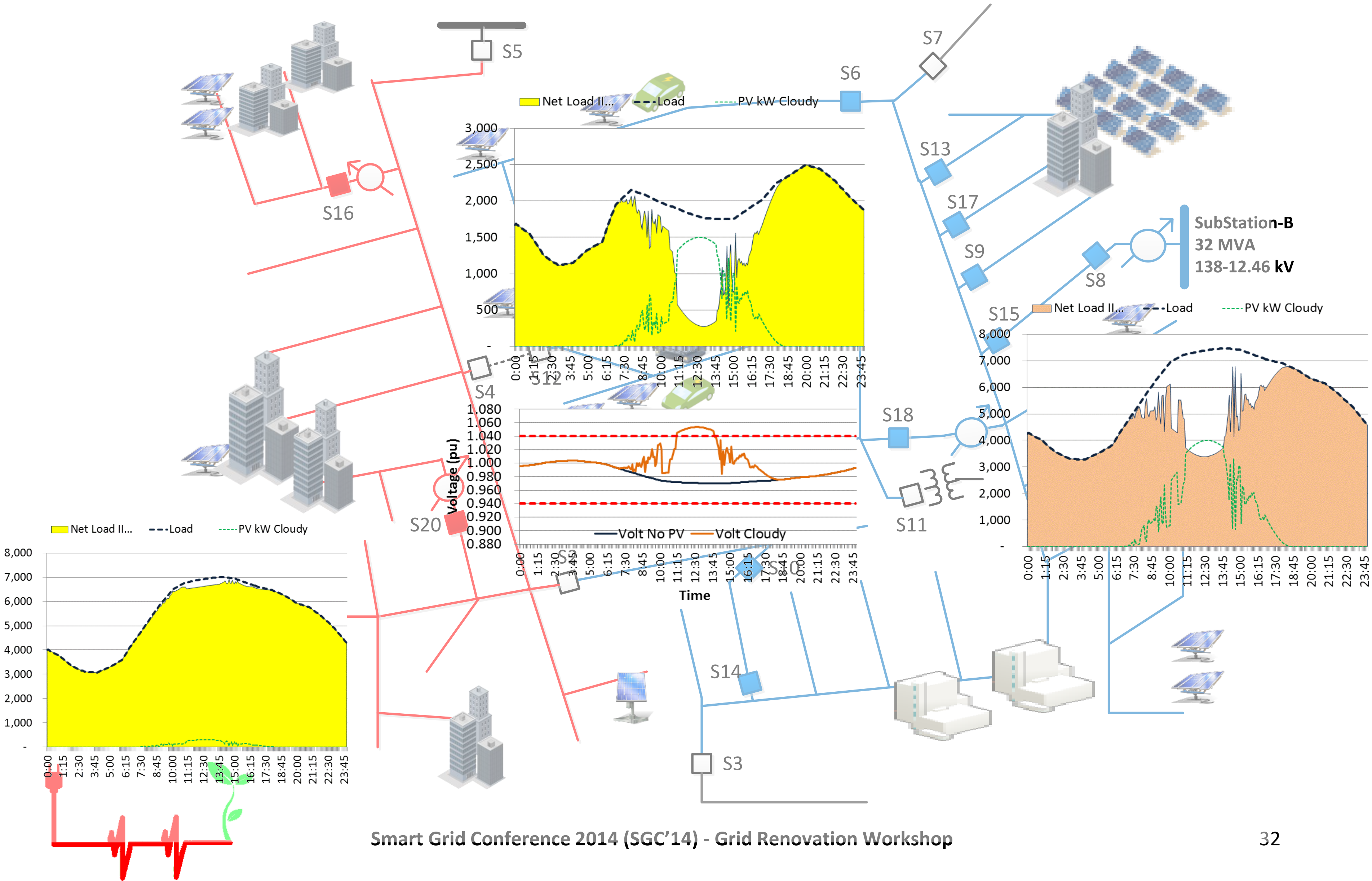
Distribution Switching Operation



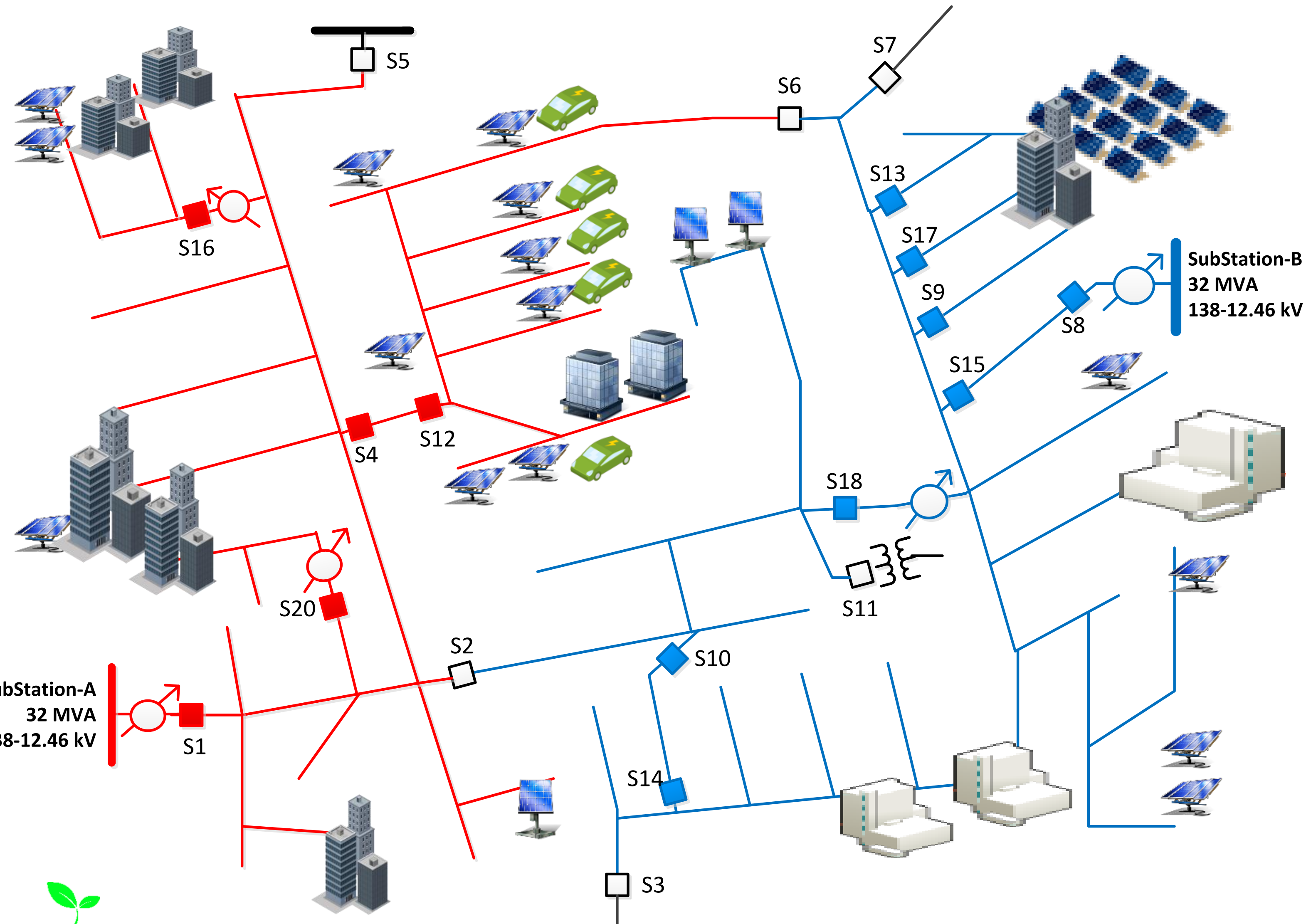
Changing Distribution Circuit Topology



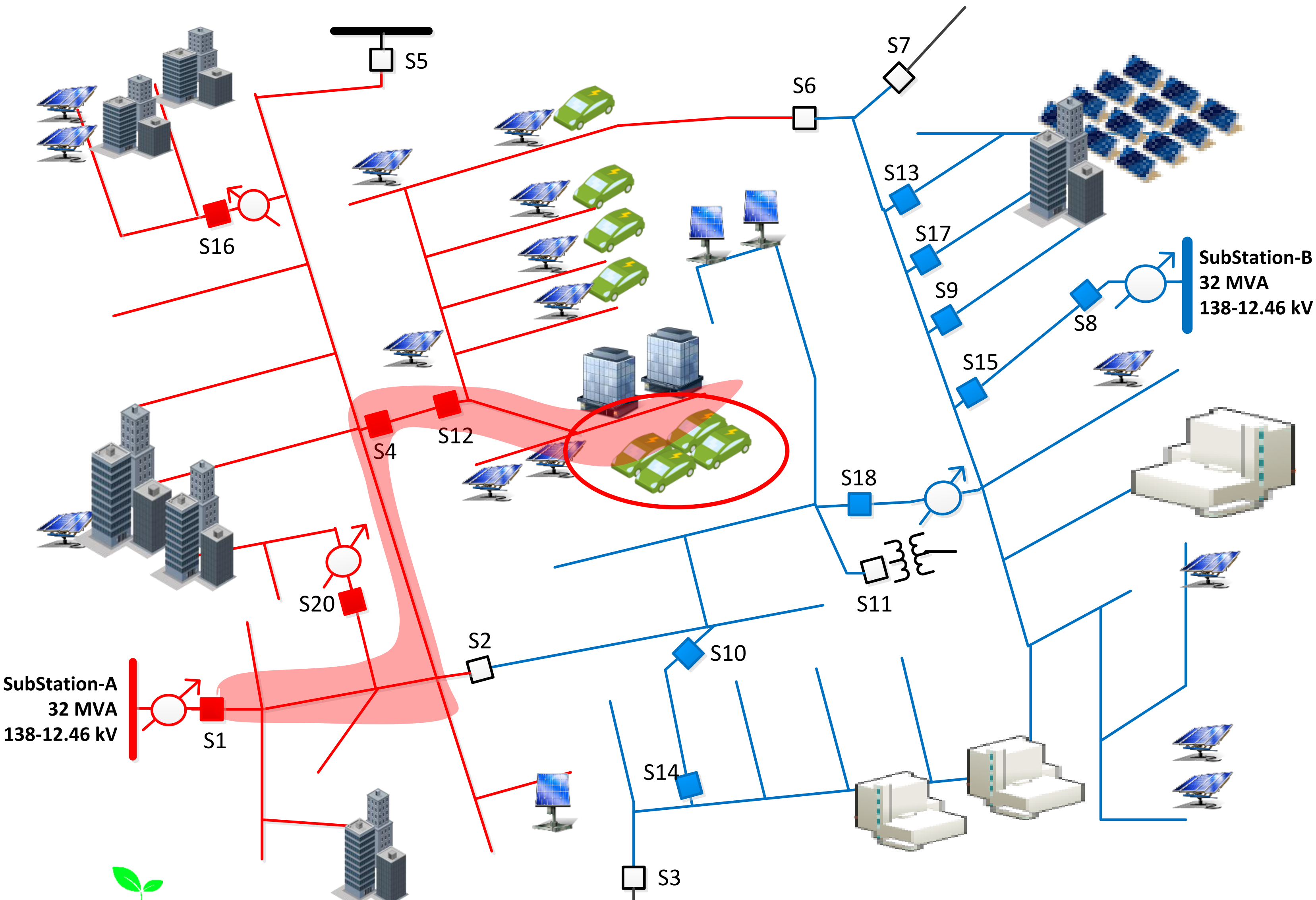
Changing Load and Voltage Profiles



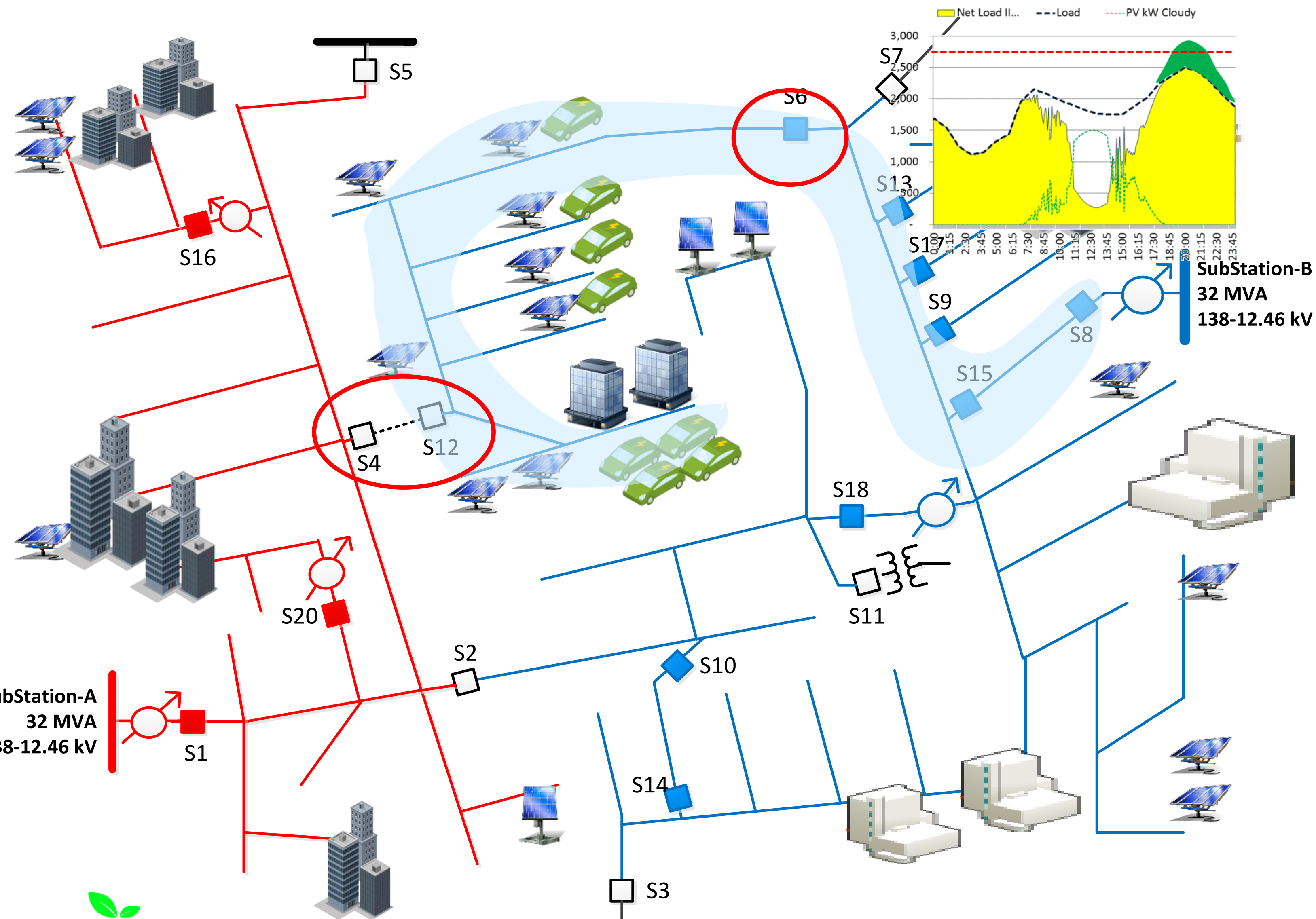
Distribution Congestion



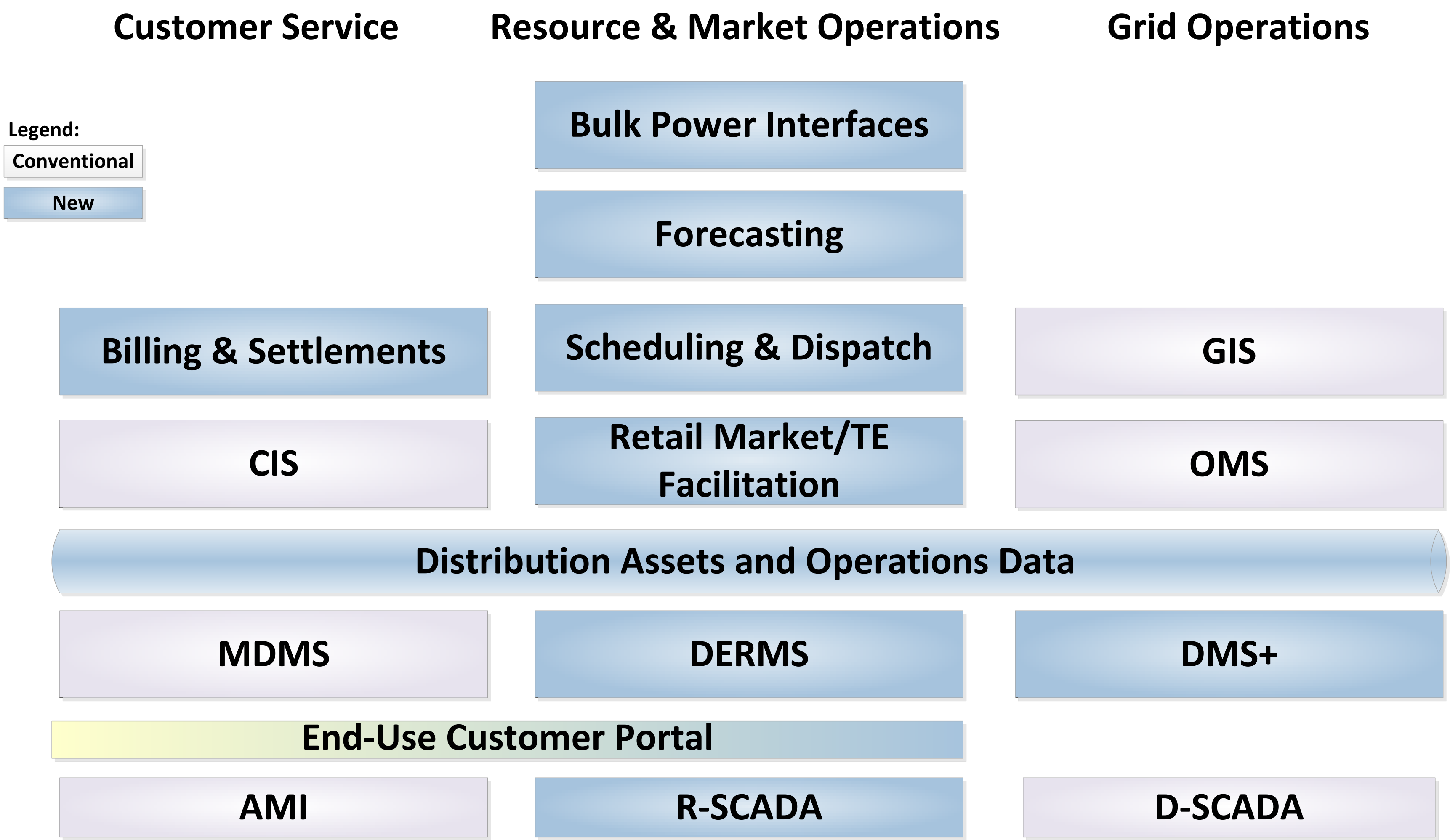
Distribution Congestion Management



Distribution Congestion Management



DSO Application Requirements



Examples of DSO Regulatory Initiatives

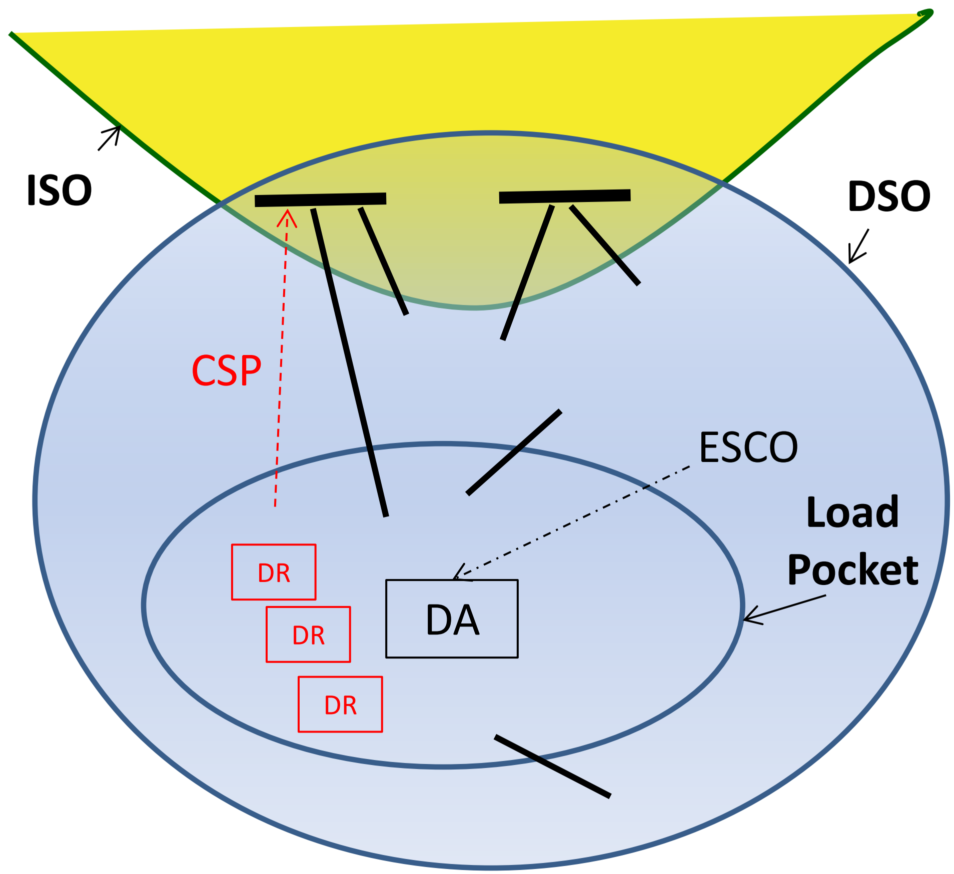
- California State Public Service Commission promoting DSO construct (Process started mid-2014)
- New York State Department of Public Service initiative for a Distributed System Platform (DSP) which includes specification of functions for a DSP Operator (Process started mid-2014)

New York State DSP Roles & Responsibilities

Utility and DSP Roles and Responsibilities	Utility	DSP
Market Functions		
Administer distribution-level markets including:		
- Load reduction Market		X
- Ancillary services		X
Match load and generator bids to produce daily schedules		X
Scheduling of external transactions		X
Real-time commitment, dispatch and voltage control		X
Economic Demand Response		X
Demand and Energy Forecasting	X	X
Aggregate Demand Response for sale to NYISO	X	X
Bid Load into the NYISO	X	
Purchase Commodity from NYISO	X	
Metering	X	
Billing	X	X
Customer Service	X	X
System Operations and Reliability		
Monitor real-time power flows	X	X
Emergency Demand Response Program	X	X
Ancillary Services	X	X
Supervisory Control and Data Acquisition	X	X
System Maintenance	X	
Engineering and Planning		
Engineering	X	
Planning / Forecasting	X	X
Capital Investments	X	
Interconnection	X	X
Emergency Response		
Outage Restoration / Resiliency	X	X

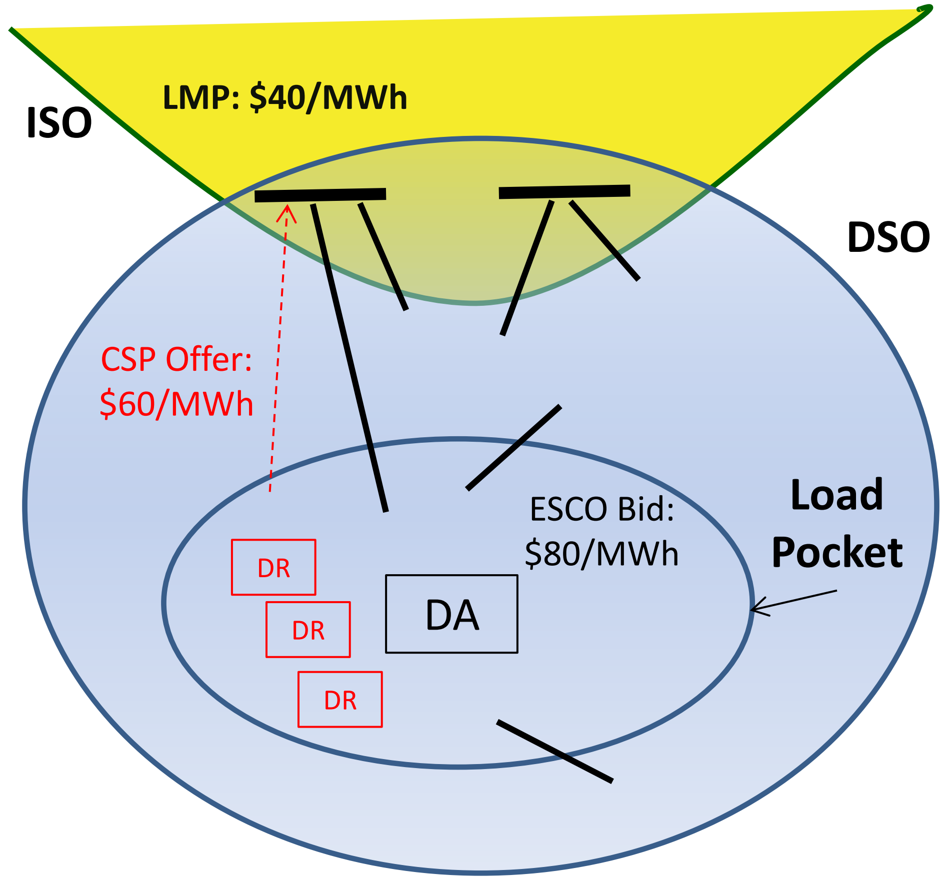
Illustrative DSO/DSP Use Case

- Load pocket in DSO Service Area
- An Energy Service Company (ESCO) has access to cheap power from resources outside load pocket and signs up a contract to supply power to a Direct Access (DA) customer cheaper than utility rate.
- There is an emergency generator at the DA customer site which is expensive to run. Based on the ESCO contract with the DA, if there is a shortfall, the emergency generator can be used but the ESCO will have to compensate the DA customer for the cost.
- A Curtailment Service Provider (CSP) has singed up a number of prosumers in the load pocket and acts as aggregator of their DR/DER capabilities to offer into an ISO market



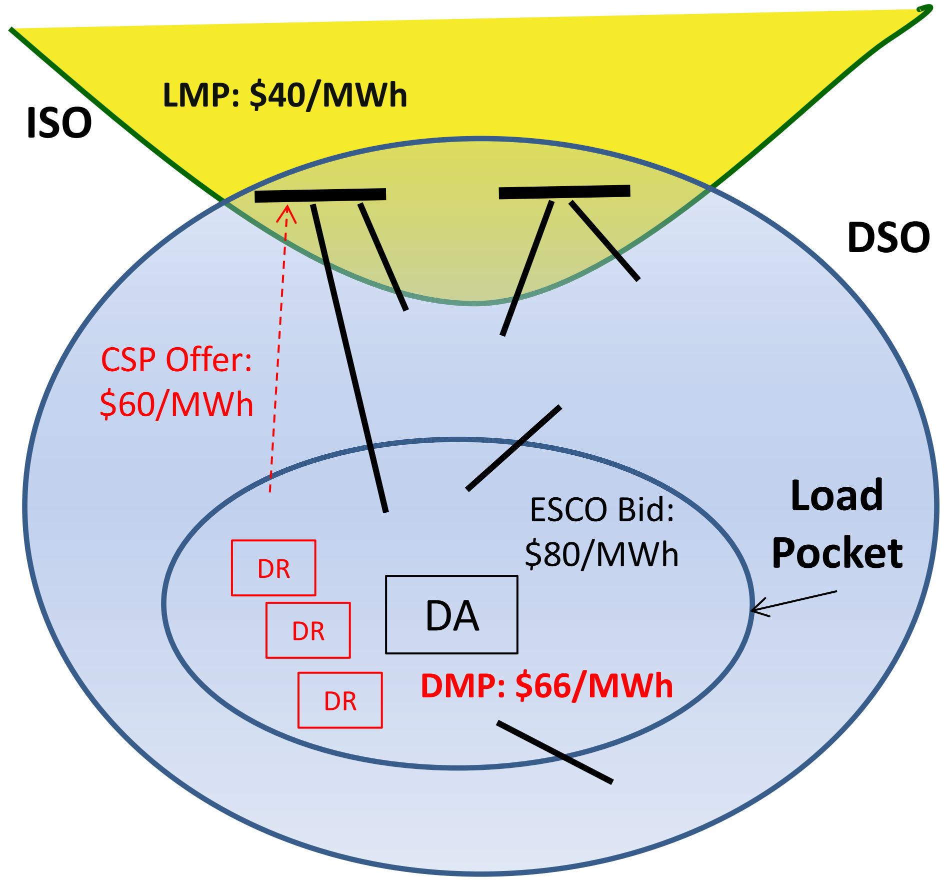
Illustrative DSO/DSP Use Case (Cont'ed)

- Forecast is for a hot day
- Load forecast within the load pocket is large due to lots of air conditioners expected to be on
- Feeders into the load pocket are at expected at their capacity limit; net load in load pocket exceeding import capacity into the pocket by 5 MW
- The ESCO bids into the DSO retail market (at \$80/MWh) to have the DSO serve any shortfall due to potential load pocket import limitations (the \$80/MWh is cheaper than the cost of running the emergency generator.)
- CSP offers Aggregated DR from within the load pocket into the ISO market (at \$60/MWh)
- There is a lot of solar generation outside the load pocket
- Wholesale market prices (LMPs at transmission substations) are moderate (\$40/MWh)



Illustrative DSO/DSP Use Case (Cont'ed)

- CPS offer does not clear the ISO market since its offer ($60/MWh) exceeds the LMP ($40/MWh)
- With no DSP platform the CSP's DR offer would be left unutilized; the expensive emergency generator would have to be operated to supply the 5 MW shortfall.
- With the DSP in place, 5 MW of DR is cleared locally against the ESCO bid and the price is set between $60/MWh and $80/MWh depending on DSP market-clearing rules (for example allowing for 10% distribution losses the price would be $66/MWh)



Challenges and Opportunities

- Opportunities
  - *The DSO construct helps promote use of preferred resources and avoid disruptive operational impacts*
  - *There are no technological barriers for implementation of fully transactive (maximalist) DSO*
- Challenges
  - *Regulatory barriers*
  - *Operator acceptance*
  - *Customer engagement*
  - *Incentive compatible market design*

Transactive Energy Paradigm

Transactive Energy

- Definition
  - "Transactive energy approaches use economic or market based constructs to manage the generation, consumption or flow of electric power within an electric power system while considering grid reliability constraints."

Proceedings of the 2nd GridWise® Architecture Council Workshop on Transactive Energy. ww.gridwiseac.org

- Some Key Characteristics
  - Coordinated distributed decision making
  - End-to-End coverage from wholesale markets to end-use devices

Wholesale vs. Retail Transactive Techniques

- Wholesale transactive tools and techniques have been developed the last two decades for management of bulk power operations in bilateral and centralized markets including:
  - *Physical and financial deals*
  - *Bidding and Scheduling*
  - *Bid-matching/market-clearing /pricing*
  - *Transmission capacity reservations and auctions*
  - *Congestion management*

Wholesale vs. Retail Transactive Techniques (Continued)

- Lessons learned from bulk power operations and wholesale energy markets can be applied to distributed resources, demand response, retail markets, and distribution system operations. These include:
  - *Scheduling and dispatch of demand-side resources with economic and reliability based objectives*
  - *Distribution congestion management and capacity reservations*
  - *Distribution capacity auction to hedge against limited distribution capacity*
  - *Variable Generation balancing using demand-side resources - scheduling and operational considerations*
- Except for Energy, products transacted in wholesale markets and used for bulk power operation do not have a corresponding counterpart in retail markets and distribution operations

Transactive Control: Definitions

- Transactive Control

  A single, integrated, smart grid incentive signaling approach utilizing an economic signal as the primary basis for communicating the desire to change the operational state of responsive assets.

- Transactive node

  A physical point within an electrical connectivity map of the system. Electrical energy flows through a transactive node.

- Transactive Incentive Signal (TIS)

  A representation of the actual delivered cost of electric power at a specific system location (e.g., at a transactive node). Includes both the current value and a forecast of future values.

- Transactive Feedback Signal (TFS)

  A representation of the net electric load (responsive and unresponsive) at a specific system location (e.g., at a transactive node) based on the balance of power flowing into, out of and consumed at the node. Includes both the current value and a forecast of future values.

Transactive Nodes

- A *transactive node* includes an agent (i.e., a computer and its software applications) that orchestrates each *transactive node's* responsibilities to
- economically balance energy
- incentivize energy consumption or generation
- activate its own responsive generation and/or load resources
- exchange both *transactive incentive signals (TIS)* and *transactive feedback signals (TFS)* with each of its neighboring *transactive nodes*.

An Incentive Signal

Predict and share a dynamic, price-like signal—the unit cost of energy needed to supply demand at this node using the least costly local generation resources and imported energy. May include

- Fuel cost
- Amortized infrastructure cost
- Cost impacts of capacity constraints
- Existing costs from rates, markets, demand charges, etc.
- Green preferences?
- Etc.

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A Feedback Signal

Predict and send dynamic feedback signal—power predicted between this node and a neighbor node based on local price-like signal and other local conditions. May include

- Inelastic and elastic load components
- Weather impacts (e.g., ambient temperature, wind, insolation)
- Occupancy impacts
- Energy storage control
- Local practices, policies, and preferences
- Effects of demand response actions
- Customer preferences
- Predicted behavioral responses (e.g., to portals or in-home displays)
- Real-time, time-of-use, or event-driven demand responses alike
- Distributed generation

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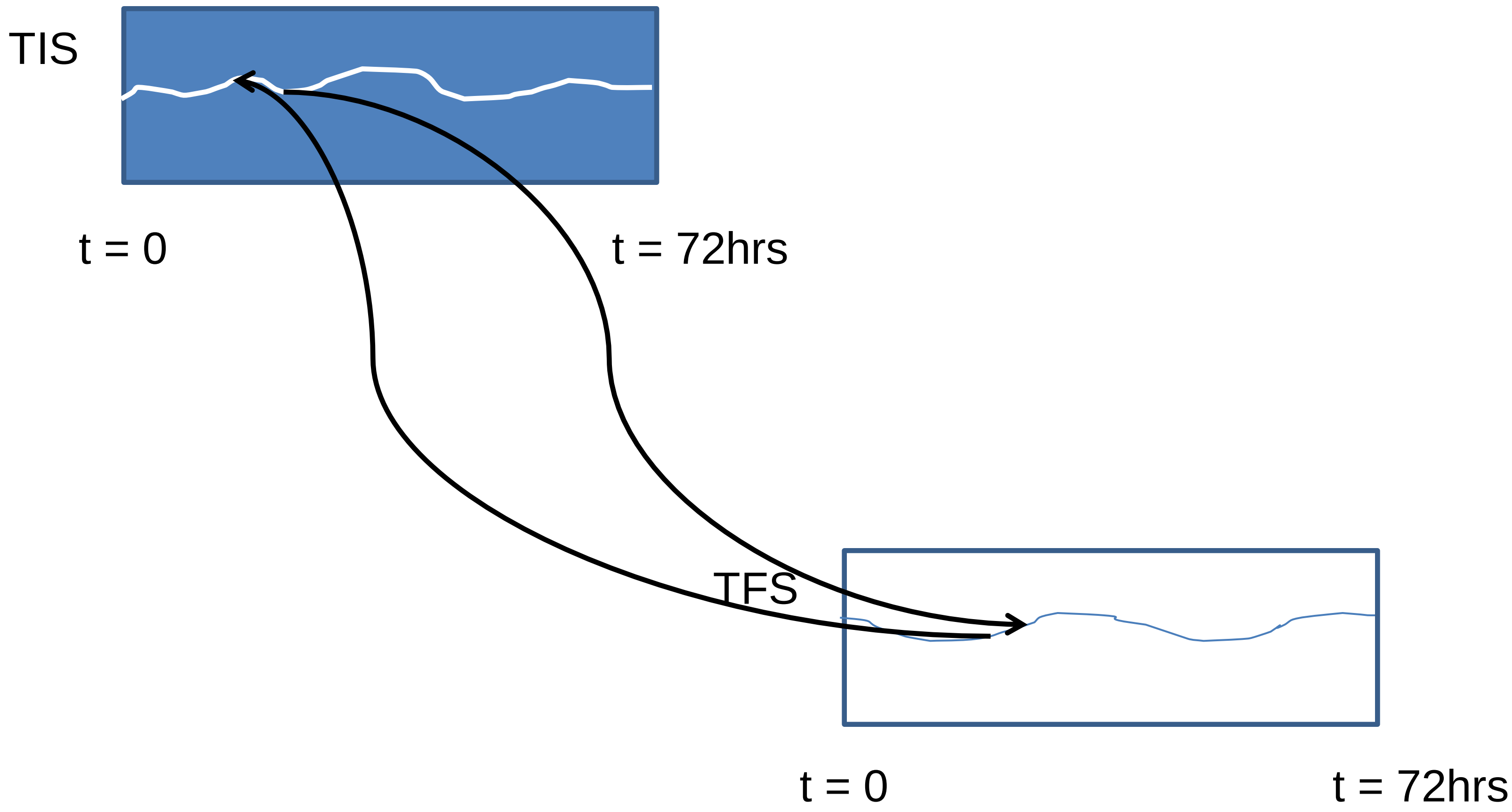
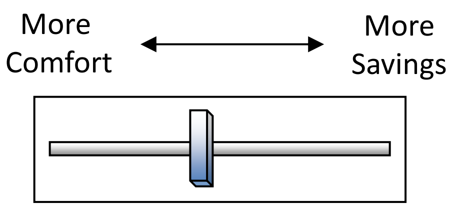
TIS-TFS Illustration

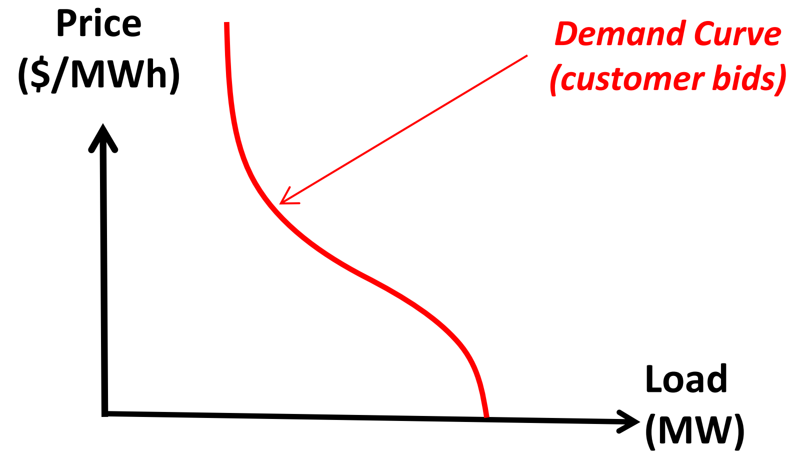


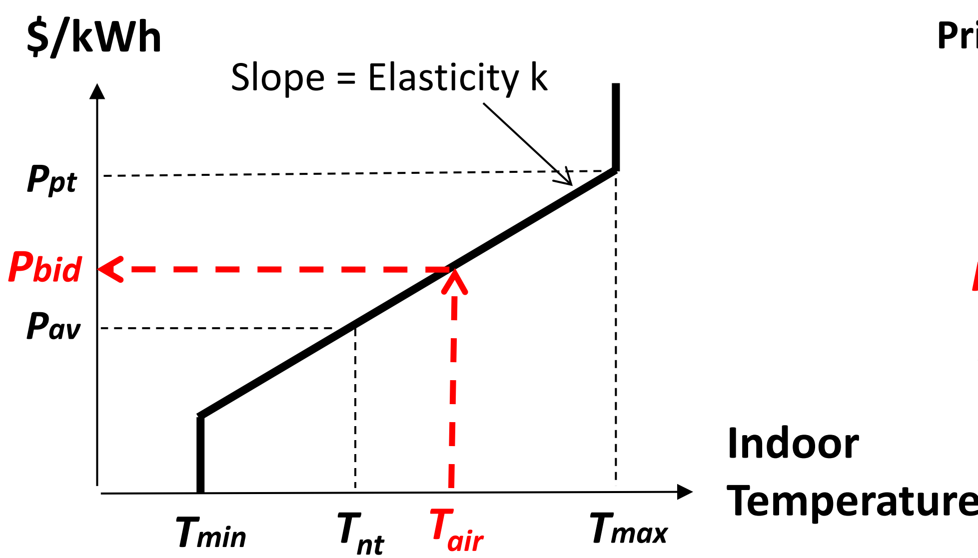
Transactive Control from Interaction of Price Discovery & Customer Bidding Algorithms

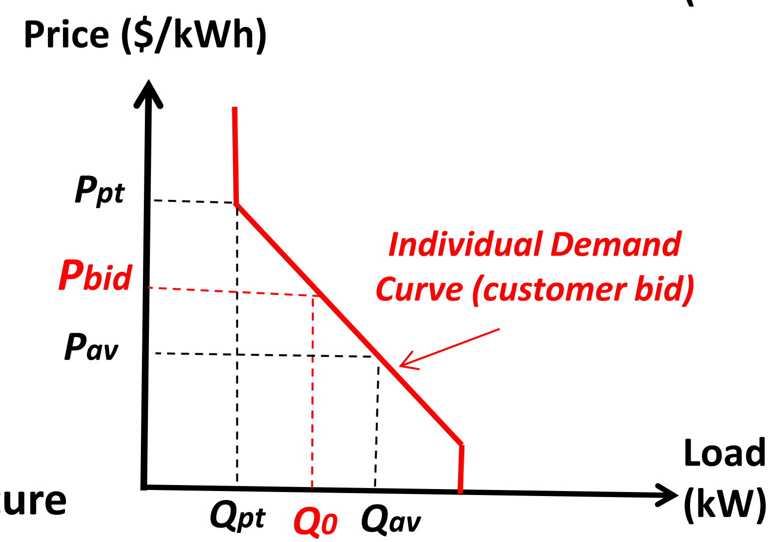
Transactive Cooling Thermostat

User Adjusts Tmin, Tmax, and Price Elasticity k







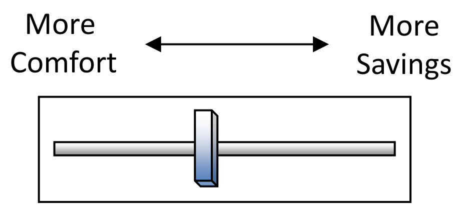


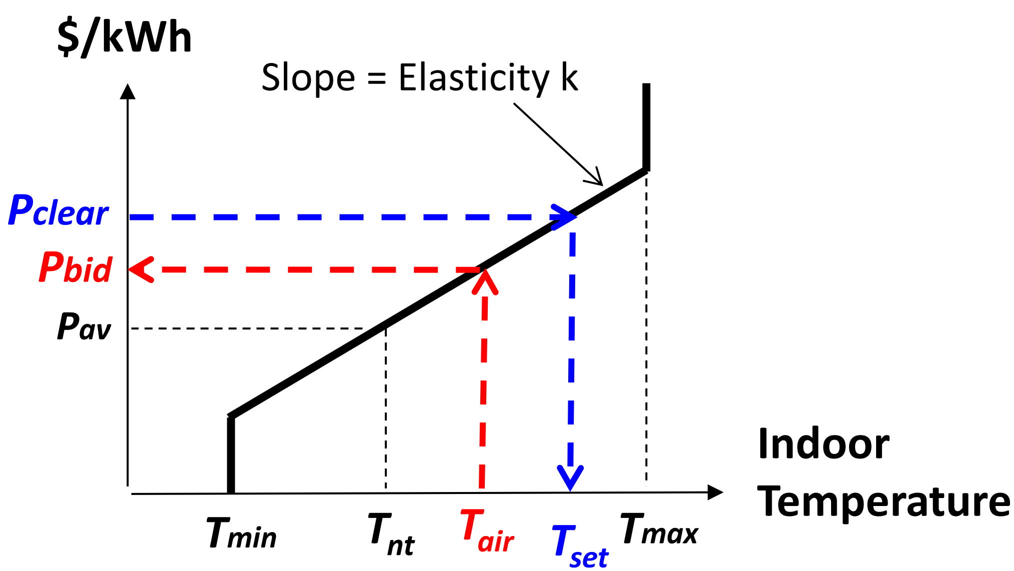
Price is *normalized*: $P^* = [\, P - \text{mean}(P) \,] \,/\, \sigma(P)$

Transactive Control from Interaction of Price Discovery & Customer Bidding Algorithms

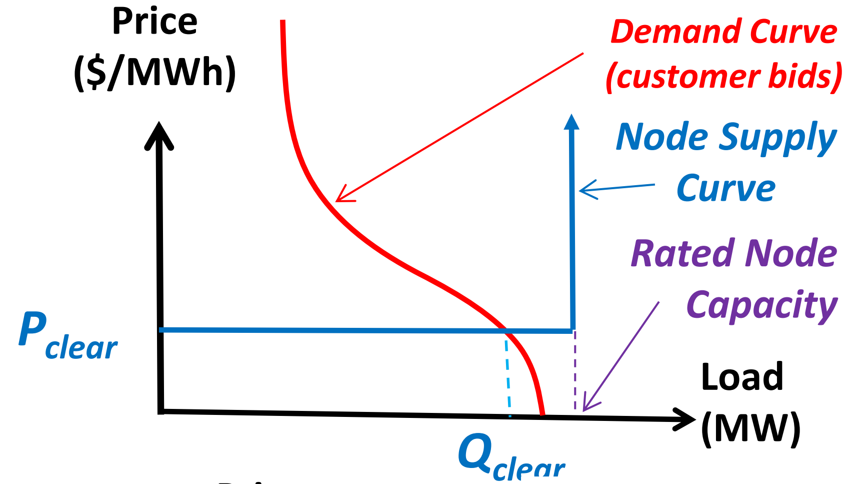
Transactive Cooling Thermostat

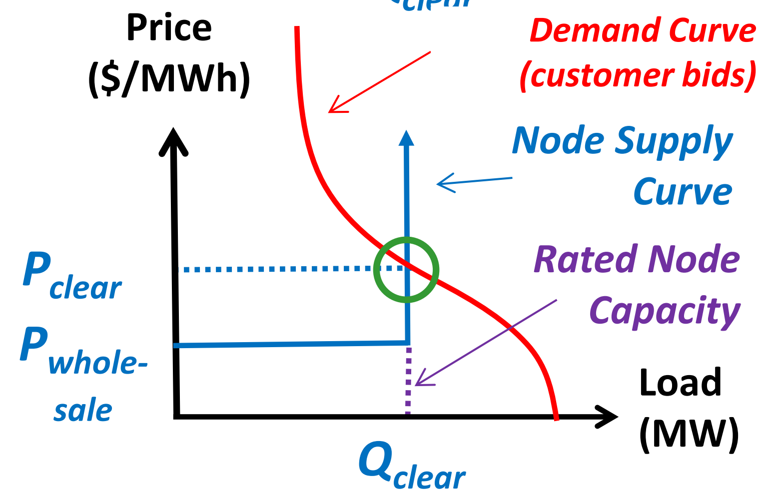
User Adjusts Tmin, Tmax, and Price Elasticity k





Real-time Market Clears Customer Bids





Price is *normalized*: $P^* = [\, P - \text{mean}(P) \,] / \sigma(P)$

Concluding Remarks

- Electric industry landscape is changing due to proliferation of renewable resources and active demand-side participation
- Emerging technologies help improve efficiency and reduce environmental impacts of energy production and consumption, but create operational problems
  - *Preferred Resources (efficiency and environment viewpoints)*
  - *Disruptive Technologies (operational viewpoint)*
- The DSO construct helps promote use of preferred resources and avoid disruptive operational impacts
- The DSO and Transactive Energy roadmaps have important touch points in the emerging industry landscape
- There are no technological barriers for implementation of fully Transactive (maximalist) DSO
- Regulatory barriers do exist. DSO scope increases as regulatory barriers are lowered

QUESTIONS